HOW TO USE THE THERMISTORS: INTRODUCTION

Each active Space Experiment Module (SEM) module contains an Module Electronics Unit (MEU). This is the power control and data acquisition system for the module experiment. The MEU can sample analog data channels and record the data to the Electrically Erasable Programmable Read-Only Memory (EEP-ROM) following the experiment timeline.

Thermistors are devices that change electrical resistance as temperature changes. The resistance usually changes exponentially with temperature. Most thermistors have an operating range of -30 degree Celsius to +120 degree C.

This guide contains the essential information to successfully implement the thermistors in an experiment. This information applies equally to the MEU and the Ground Module Electronics Unit (GMEU). For further information on the analog measurement capabilities and interfacing please refer to the "How to Use the Analog Resources" document.

HOW TO USE THE THERMISTORS: MAKING TEMPERATURE MEASUREMENTS

The Module Electronics Unit (MEU) uses an analog-to-digital converter chip to convert a Voltage to data. All measurements are initiated by timeline commands. The data is then stored in the MEU memory as raw data, and not a temperature value. The data must be processed after the flight and convert or interpret the data as a temperature.

MEU Analog-to-Digital (A/D) Converter

The MEU has a 12-bit A/D converter (MAX191) which measures analog data. The A/D converter can only accept input Voltages ranging from 0 to +5 Volts Direct Current (VDC). The micro-controller in the MEU records the A/D's measurement in binary on the Electrically Erasable Programmable Read-Only Memory (EEPROM) according to the experiment timeline. The data is stored in two bytes, with the most significant byte containing the channel number (first four bits) and the first four bits of data. The second byte contain the last eight bits of the 12-bit measurement. For purposes of this discussion the binary data will be represented in hexadecimal. The digital measurement ranges from 000h (hexadecimal) to FFFh (or 0 to 4095 in decimal). This means that the five volt span of the converter is divided up into 0.001 Volt (V) steps.

Resolution and Accuracy

To be supplied.

Data Conversion

Formulas for MEU to be supplied.

Sampling Rates

A total of nine sampling rates are available. See Table 2.4 below. Each sample will occupy two bytes of memory in the MEU EEPROM. The system is designed to measure discrete Voltages and not sample waveform shapes.

Figure 2.4 MEU Analog Sampling Rates

Rate No.	Rate Identification	Description	Samples/Hour
0	ZERO	No Sampling	0
1	ONCE	Sample Once	-
2	10 MIN	Sample Every 10 Minutes	6
3	5 MIN	Sample Every 5 Minutes	12
4	1 MIN	Sample Every 1 Minutes	60
5	10 SEC	Sample Every 10 Seconds	360
6	5 SEC	Sample Every 10 Seconds	720
7	1 SEC	Sample Every 10 Seconds	3600
8 0.	2 SEC	Sample Every 10 Seconds	18000

Thermistor Data

The MEU measure the temperature and comes up with a 12-bit binary number. As discussed above, over a 0 to +5V range, it can measure raw temperature data to within 0.001V (or 1 megavolt (mV)). Using a YSI 44006 thermistor, this translates into an resolution of about 0.04 C. In practice there tends to be some noise in the system that bring the accuracy of a measurement to about 0.5C. Since the thermistor curve is not linear, the accuracy decreases at the extremes. Figure 6.1 show a typical thermistor curve. The data is in decimal for 0 to 4096 (12-bit data). Additional information on the YSI 44006 thermistor is located in Appendices A and B.
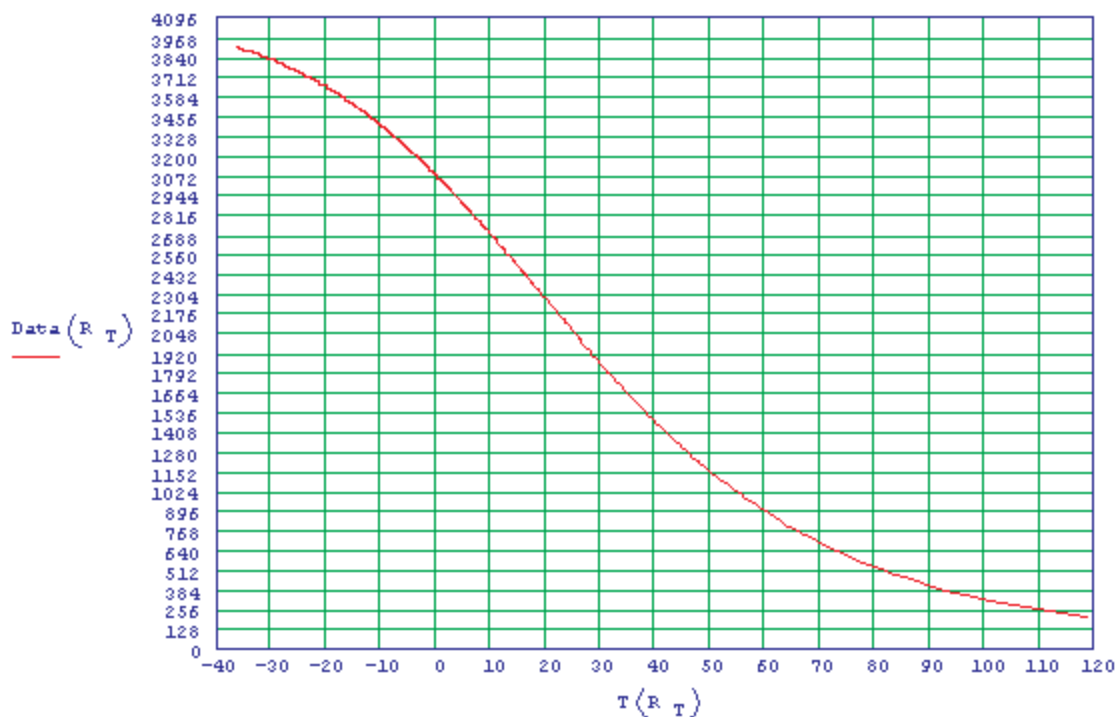

### Figure 2.5 - YSI 44006 Thermistor Curve

HOW TO USE THE THERMISTORS: HOOKING UP THE THERMISTORS

This section describes how to electrically and physically install a thermistor. The three Module Electronics Unit (MEU)/Ground Module Electronics Unit (GMEU) experimenter thermistor channels are the simplest to use. However, the six additional experimenter analog inputs that can be converted into thermistor channels with the use of a resistor.

The recommended thermistor to use is a YSI 44006 (10 Kelvin (K) @25). It is advantageous to use this part since the Space Experiment Module (SEM) software is designed to convert and plot temperature data in degrees Celsius for the YSI 44006 only. This part is commercially available and can be purchased from a number of mail order electronic part vendors. (Refer to the "How to Find Parts and Materials" document.) Other thermistors may be used, but a new data curve will need to be generated by the experimenter.

HOOKING UP TO THE THERMISTORS CHANNELS

The MEU has three dedicated thermistor channels using six dedicated pins on the experiment connector. Thermistors can be hooked up directly to the these pins. (See Figure 3.1.) This is the simplest and most common way to connect up to three thermistors. Please note that there are separate grounds for the thermistors and the analog channels. The thermistors are required to use the corresponding thermistor grounds as listed in Table 3.1.
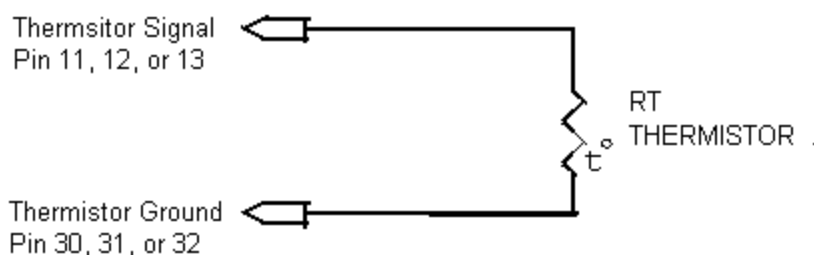
Figure 3.1 - Thermistor Circuit for Thermistor Channels Only

Channel (Dec.)	Channel (HEX)	Thermistor Channels	Thermistor Signal Pin Numbers	Thermistor Signal Return Numbers
0	0	Experiment Thermistor #1	11	30
1	1	Experiment Thermistor #2	12	31
2	2	Experiment Thermistor #3	13	32

MEU Thermistor Channels

HOOKING UP THERMISTORS TO THE EXPERIMENTER ANALOG CHANNELS

Additional thermistors can be added using the general purpose analog channels and the +5 Volt (V) Sensor Power (pin 34). Use the circuit in Figure 3.2. This circuit must be referenced to the Analog Signal Ground. For best accuracy use a 10K Ohm, 1/4 Watt, 1% tolerance resistor. Capacitor C1 is optional, and a YSI 44006 thermistor is recommended. Other type of resistive transducers can use this type of circuit.
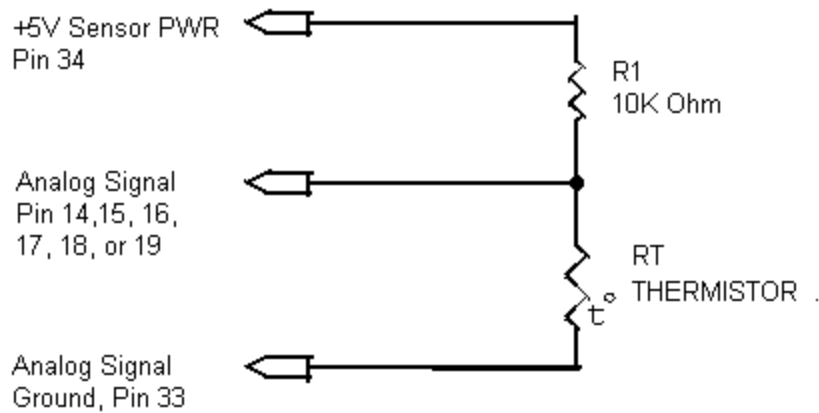

*Figure - Thermistor Circuit for Experimenter Analog Channels Only*

Channel (Dec.)	Channel (HEX)	Thermistor Channels	Thermistor Signal Pin Numbers	Thermistor Signal Return Numbers
3	3	Experiment Analog #1 (0 to +5 V)	14	33
4	4	Experiment Analog #2 (0 to +5 V)	15	33
5	5	Experiment Analog #3 (0 to +5 V)	16	33
6	6	Experiment Analog #4 (0 to +5 V)	17	33
7	7	Experiment Analog #5 (0 to +5 V)	18	33
8	8	Experiment Analog #6 (0 to +5 V)	19	33
14	E	+5V Sensor Power (10 miliampere (mA) maximum.)	34	33

MEU Analog Resources

INSTALLING THERMISTORS

The following steps were devised for physically installing the thermistor on a pair of wires. These devices are very delicate and the leads are very thin. It is important to take your time. Expect to spend at least one hour per thermistor. This is only a recommend method of installation and may not be appropriate for every application. This method is not foolproof.
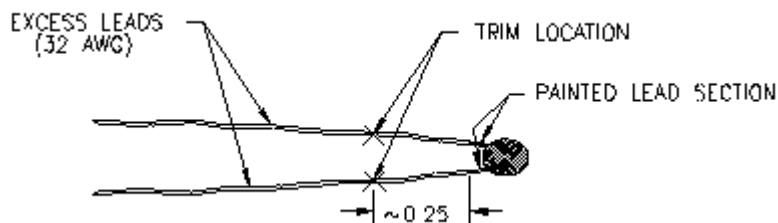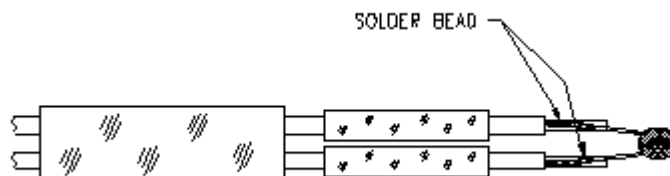
TRIM THERMISTOR LEADS TO APPROXIMATE LENGTH OF 0.25 INCHES (+0.10. -0.05) BEYOND PAINTED LEAD SECTION.
STEP 1
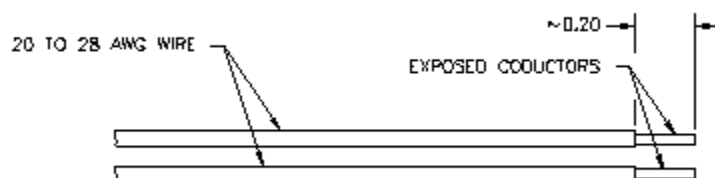
REMOVE THE INSULATION TO EXPOSE APPROXIMATELY 0.20 In (+0.20. -0.00) OF CONDUCTOR LENGTH AND TIN.
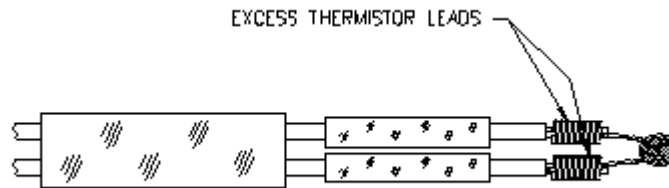**STEP 2**
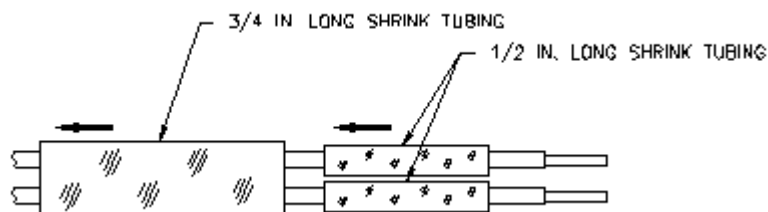
SLIDE SHRINK TUBING, OVER WIRE AS SHOWN ABOVE AND POSITION AWAY FROM END.
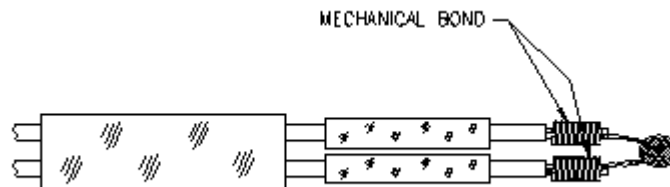SHRINK TUBING SHOULD BE SIZED FOR WIRE BEING USED.
STEP 3

ATTACH THERMISTOR ONTO WIRE BY APPLYING A TACK BEAD OF SOLDER.
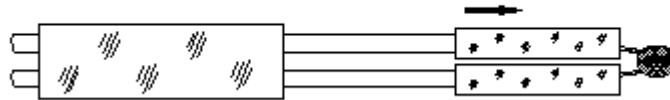**STEP 4**

Steps 5-8 on the next page.

WRAP EXCESS THERMISTOR LEADS IN A TIGHT SPIRAL PATTERN AROUND CONDUCTOR WITH A MINIMUM OF THREE TURNS
STEP 5

SOLDER THERMISTOR LEADS (FORMING A MECHANICAL BOND), CLEAN, AND INSPECT.
STEP 6

SLIDE AND INSTALL 1/2 INCH LONG SHRINK TUBING OVER SOLDERED CONNECTIONS, MINIMIZING EXPOSED THERMISTOR LEADS. DO NOT HEAT THE THERMISTOR FOR MORE THAN 10 SECONDS AT A TIME TO PREVENT DAMAGE TO THE COMPONENT.
STEP 7
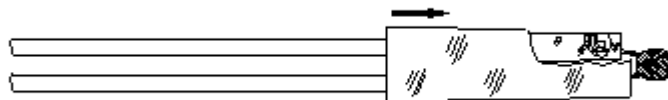
ATTACH THERMISTOR ONTO WIRE BY APPLYING A TACK BEAD OF SOLDER.
STEP 8

After the wires are attached the thermistor should be tested (see Section 4.0) before it is bonded to thermal target. It is highly desirable to use a thermally conductive compound for bonding.

HOW TO USE THE THERMISTORS: TESTING AND TROUBLESHOOTING

Simple Functional Test
To be supplied.

Test with a Ground Module Electronics Unit (GMEU)
To be supplied.

Calibration
To be supplied.

Common Problems
To be supplied.

HOW TO USE THE THERMISTORS: GENERAL RULES

The following general rules are a summary of the important point discussed above. This list of rules can be used as a checklist to help ensure your mission success.

Use YSI-44006 thermistors.
• If using three or less thermistors, connect then to the dedicated thermistor channels as shown in Hooking Up Thermistors Section.
• Test the thermistor as in the Trouble Shooting Section before and after bonding then to a surface.
• Test the thermistor with the Ground Module Electronics Unit (GMEU) and verify that it is working properly.

HOW TO USE THE THEMISTORS: APPENDIX A — CONNECTOR PIN OUT

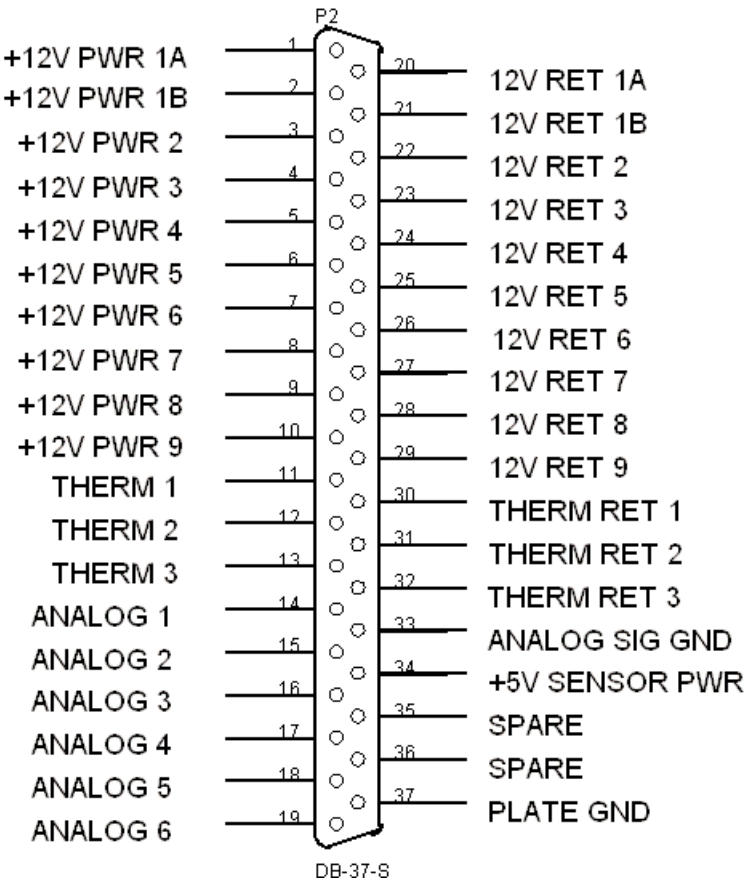Experimenter Connector Pin-out with Highlighted Thermistor Connections

P2

Pin	Signal		Pin	Signal
1	+12V PWR 1A		20	12V RET 1A
2	+12V PWR 1B		21	12V RET 1B
3	+12V PWR 2		22	12V RET 2
4	+12V PWR 3		23	12V RET 3
5	+12V PWR 4		24	12V RET 4
6	+12V PWR 5		25	12V RET 5
7	+12V PWR 6		26	12V RET 6
8	+12V PWR 7		27	12V RET 7
9	+12V PWR 8		28	12V RET 8
10	+12V PWR 9		29	12V RET 9
11	THERM 1		30	THERM RET 1
12	THERM 2		31	THERM RET 2
13	THERM 3		32	THERM RET 3
14	ANALOG 1		33	ANALOG SIG GND
15	ANALOG 2		34	+5V SENSOR PWR
16	ANALOG 3		35	SPARE
17	ANALOG 4		36	SPARE
18	ANALOG 5		37	PLATE GND
19	ANALOG 6			

DB-37-S

Table: Experimenter Connector Signal

Pin No.	Signal Name	Signal Description	Limits
1	+12V PWR 1A (Port 1)	12V Power Output	2.5A maximum
2	+12V PWR 1B (Port1)	12V Power Output	2.5A maximum
3	+12V PWR 2 (Port 2)	12V Power Output	1A maximum
4	+12V PWR 3 (Port 3)	12V Power Output	1A maximum
5	+12V PWR 4 (Port 4)	12V Power Output	1A maximum
6	+12V PWR 5 (Port 5)	12V Power Output	1A maximum
7	+12V PWR 6 (Port 6)	12V Power Output	1A maximum
8	+12V PWR 7 (Port 7)	12V Power Output	1A maximum
9	+12V PWR 8 (Port 8)	12V Power Output	1A maximum
10	+12V PWR 9 (Port 9)	12V Power Output	1A maximum
11	THERM 1	Experiment Thermistor 1	0 to +5 VDC
12	THERM 2	Experiment Thermistor 2	0 to +5 VDC
13	THERM 3	Experiment Thermistor 3	0 to +5 VDC
14	ANALOG 1	Experiment Analog 1	0 to +5 VDC
15	ANALOG 2	Experiment Analog 2	0 to +5 VDC
16	ANALOG 3	Experiment Analog 3	0 to +5 VDC
17	ANALOG 4	Experiment Analog 4	0 to +5 VDC
18	ANALOG 5	Experiment Analog 5	0 to +5 VDC
19	ANALOG 6	Experiment Analog 6	0 to +5 VDC
20	12 RET 1A (Port 1)	Port 1 Power Return	Used with +12V PWR 1A
21	12 RET 1A (Port 1)	Port 1 Power Return	Used with +12V PWR 1B
22	12 RET 2 (Port 2)	Port 2 Power Return	Used with +12V PWR 2
23	12 RET 3 (Port 3)	Port 3 Power Return	Used with +12V PWR 3
24	12 RET 4 (Port 4)	Port 4 Power Return	Used with +12V PWR 4
25	12 RET 5 (Port 5)	Port 5 Power Return	Used with +12V PWR 5
26	12 RET 6 (Port 6)	Port 6 Power Return	Used with +12V PWR 6
27	12 RET 7 (Port 7)	Port 7 Power Return	Used with +12V PWR 7
28	12 RET 8 (Port 8)	Port 8 Power Return	Used with +12V PWR 8
29	12 RET 9 (Port 9)	Port 9 Power Return	Used with +12V PWR 9
30	THERM RET 1	Thermistor 1 Return	Used with THERM 1
31	THERM RET 2	Thermistor 2 Return	Used with THERM 2
32	THERM RET 3	Thermistor 3 Return	Used with THERM 3
33	ANALOG SIG GND	Analog Signal Ground	Used with ANALOG 1 - 6
34	+5V SENSOR PWR	+5V Sensor Power 1	0 Milliampere (mA) max.
35	SPARE	SPARE	Do not use
36	SPARE	SPARE	Do not use
37	PLATE GND	Plate or Chassis Ground	Single Point Ground

HOW TO USE THE THERMISTORS: APPENDIX B — THERMISTOR FORMULAS

These formulas are for the YSI 44006 thermistor.

R = resistance in Ohms

T = temperature in Kelvin

Constants:

a = 0.0010295

b = 0.0002391

c = 1.568E-7

Have T want R:

R = e exp[(beta -(alpha/2))^(1/3) - (beta+(alpha/2))^(1/3)]

where alpha = (a - (1/T))/c

and beta = [(b/(3*c))^3 + (alpha^2)/4]^(1/2)

Have R want T:

T = 1/[a + b*ln(R) + c*((ln(R))^3)]

HOW TO USE THE THEMISTORS: APPENDIX C — SEM THERMISTOR CIRCUIT ANALYSIS

By: Ken McCaughey/CTA Inc.

File: sem_temp.mcd

Date: 24-Jul-96

Revision: A

NOTE: This analysis is based on the thermistor analysis developed for the SPRE experiment (SPRE-ANYS-010).

THERMISTOR SENSOR FORMULA

YSI-44006 temperature vs. resistance. Resistance (R) is in Ohms and Temperature (T) in degrees Celsius (C):

A = 0.0010295   B = 0.0002391   C = 1.568-10-7

C = K

Note: Formula provided by YSI Inc.

Resistance values at selected temperatures (in degrees C):

Rm30 = 135200 - ohm T(Rm30) = -29.864 *C

R0 = 29490 - ohm T(R0) = 0.134 *C

R25 = 10000 - ohm T(R25) = 25.133 *C

R50 = 3893 - ohm T(R 50) = 50.132 *C

R100 = 816.8-ohm T(R 100) = 100.13 *C

THERMISTOR CIRCUIT ANALYSIS

Thermistor circuit:
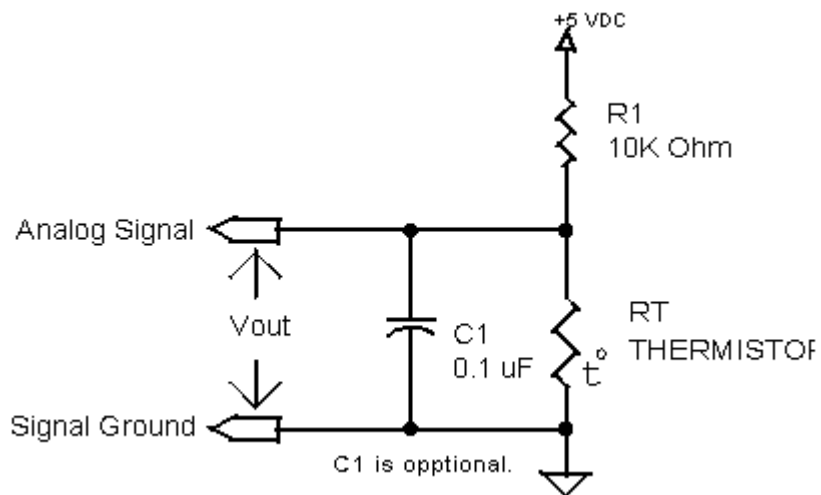
RT = thermistor (10K Ohm @ 25 C)

Circuit analysis equation with component values:

V in   = 5.0-volt

V

R1 = 10.0 * 10 3 * ohm

$$V_{out}(R_T) := V_{in} \cdot \left(\frac{R_T}{R_1 + R_T} \right)$$

Various data points:

V out(R m30) = 4.656 * volt @ -30 C

V out(R 0) = 3.734 * volt @ 0C

V out(R 25) =2.5 * volt @+25 C

V out(R 50) = 1.401 * volt @ +50 C

V out(R 100) = 0.378 * volt @ +100 C

Power dissipation in thermistor:

$$P_{RT} := \frac{V_{in}^{2}}{R_{1}}$$

P RT = 2.5 - 10-3 - watt

Maximum Voltage spread over -30C to +100C:

V diff = V out(R m30) - V out (R 100)

V diff = 4.278 * volt

Raw data calculation:

Bits = 12 Number of data bits.

V hi = V in

$$Data\left(R_{T}\right) := \frac{V_{out}\left(R_{T}\right)}{\left(\dfrac{V_{hi}}{2^{Bits}}\right)}$$

TEMPERATURE VS. RAW DATA
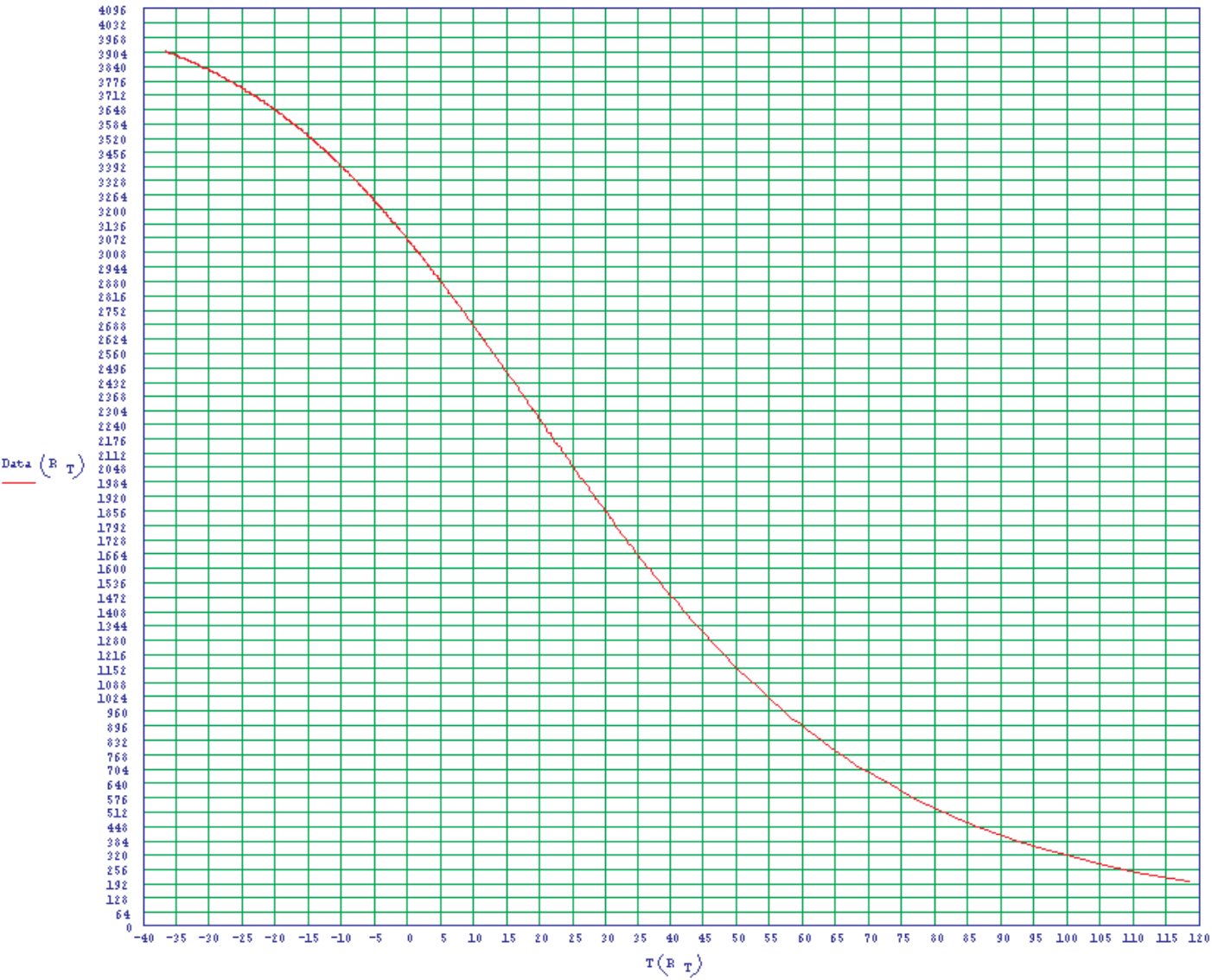
TEMPERATURE VS. OUTPUT Voltage